SECTION II.—GENERAL METEOROLOGY.

5. /

THE INFLUENCE OF A WESTERN YELLOW PINE FOREST ON THE ACCUMULATION AND MELTING OF SNOW.

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CONTENTS.

PURPOSE OF THE STUDY.

The influence of a virgin western yellow pine forest on the accumulation and melting of snow was studied at the Fort Valley Experiment Station, Arizona, during the winters of 1910–11 and 1912–13 upon two areas, alike in all respects, except that one was forested and the other naturally treeless.

THE REGION.

Topography.—The areas studied lie within the Coconino National Forest on the Colorado Plateau, at the base of the San Francisco Mountains, the highest peak of which rises to an elevation of 12,794 feet above sea level. The plateau has an average elevation of from 6,000 to 8,000 feet above sea level, and is almost uniformly covered by a western yellow pine forest. The forested portion of the plateau below the yellow pine type, from 6,500 to 5,000 feet, is covered by three species of juniper, the piñon pine, several species of oak, and other hardwoods. On the slopes above 8,500 feet the principal species are Douglas fir, white fir, corkbark fir, limber pine, bristle cone pine, and Engelmann spruce.

Climate.—The climate of the region shows very marked seasonal changes, and great variations between day and night temperatures. Forests are found only at elevations above 5,000 feet. The lowlands between the mountain ranges support nothing but desert vegetation.

The average annual precipitation in the western yellow pine forest on the Colorado Plateau amounts to approximately 24 inches. Instead of being equally distributed throughout the year, it occurs in two well-defined periods, during July and August in the form of thunder showers, and from November to April in the form of snow. The period intervening between the winter snows and the summer rains, from about April 15 to July 15, is marked by desiccating high winds from the southwest. These three months of drought are exceedingly trying to vegetation. The importance, therefore, of snow as a source of water supply for irrigation projects, stock interests, and various allied industries is obvious.

Forests and parks.—In Arizona, western yellow pine grows naturally in open stands, the trees forming small, practically even-aged groups of from 2–20 individuals with various sized openings between. These openings, comprising usually not more than half an acre, make up approximately 65 per cent of the total area of the western yellow pine forest in this region.

Occasionally these openings are very large, covering several square miles, and have agricultural value. The origin of these "parks" or treeless areas, which are typical of the whole plateau, is still an undecided question.

Fort Valley Park.—Fort Valley Park, from which the experiment station takes its name, covers about 3.4 square miles and lies 9 miles northwest of the town of Flagstaff in the Coconino National Forest. The park is practically level and has an average elevation of about 7,250 feet above sea level. The general drainage is toward the southeast. The timberland surrounding the park, except in one or two places, rises on a very gentle slope. The outline of the park is irregular, with tongues of timberland jutting out into it at various places. Together with the timberland immediately surrounding it, it constitutes a partial basin opening to the southeast, with a rim formed by the San Francisco Mountains on the north and east, Wing Mountain on the west, and Crater Mountain on the south. Between these mountains ridges or mesas rise from 100 to 200 feet above the level of the park, completing the rim.

The soil in both park and forest consists of a clay loam mixed with volcanic rock fragments and underlain by cinders which usually occur in the form of alternate compact and loose layers, beginning from 16 to 30 inches below the surface. In the forest the surface is generally covered with rocks, while in the parks the soil is fine and alluvial, having been washed in from the surrounding higher areas now occupied by the forest.

About two-thirds of the park is under cultivation, the remainder being covered with gramma grass and a variety of annual and perennial herbs. In the forest bunch grasses take the place of the gramma grass.

METHOD AND CHARACTER OF OBSERVATIONS.

Snow depth.—The snow depth was measured by means of vertical stakes marked off in feet and inches. One series of 10 stakes, 2 by 2 inches by 5 feet, was placed in the park and another series in the forest. The ground cover around the stakes was disturbed as little as possible.

The stake line was adjacent to the meteorological station of the park and represented average park conditions. (See fig. 1.) The site slopes slightly to the north. In the winter of 1910–11 the stake line extended in a northwesterly direction from the meteorological station and the 10 stakes were set at intervals of from 40 to 50 feet. In the winter of 1912–13 the stake line extended due north from the same station, with 10 stakes set at intervals of one chain or 66 feet.

A line of 10 stakes was set up in the adjacent forest, as shown, immediately south of the forest meteorological station. In order to make the forest stake line comparable to the park line, it was necessary to locate the stakes in the forest on a southerly slope of from 2 to 5 degrees, thus tending to make the records of melting of the snow in the forest higher than for the forest as a whole. In both winters the stakes were set at irregular intervals in order to represent conditions in the openings and under the groups of trees. Five of the stakes were located in various positions under the crowns of trees, and the other five in various positions in the openings. Thin 3-foot strips divided into inches and tenths of inches were attached to the stakes of both lines for the sake of more accurate measurement. In order that there might be no error in depth readings on account of the formation of small hollows around the stakes by radiation, measurements were made by laying a long thin stick on top of the snow and its line of intersection with the stake taken as the reading.

Measurements were taken immediately before and after each snowfall, whenever possible, and the readings on the park and forest stakes averaged separately. Whenever it was not practicable to take measurements immediately before and after a storm, it was always possible to take them before any appreciable settling of the new snow had occurred, and it was invariably possible to distinguish between the old and new layer of snow, and thus determine the depth of each. Care was taken to keep the snow cover around the stakes unbroken.

Measurement of melting.—The snow stakes were also used to determine the rate of melting. In the winter of 1910–11, measurement of melting was taken almost daily at the meteorological stations in conjunction with the meteorological observations. In 1912–13, daily measurements of melting, with meteorological readings, were always possible.

In the winter of 1910–11 a series of photographs (see figs. 6–9) was taken every week along both stake lines to illustrate the difference in the character of melting in the forest and park.

Water equivalents.—For determining the water equivalent of snow, a section of average depth was cut out with the overflow can of the standard raingage, and melted in a known quantity of hot water. This method is very simple, and was found to be the most accurate.

In the winter of 1910–11, water equivalents were determined only in connection with snowfall. In 1912–13, in addition to this, weekly water equivalent determinations were made of the total snow on the ground in the forest and in the park.

After the total disappearance of snow in the park, drifts of snow remained in the forest. The total water equivalent of these drifts was determined at intervals of a few days until their disappearance.

Soil moisture.—In order to determine the relative amounts of snow water absorbed by the soil in the forested and nonforested areas, and the retention of this snow water, a series of soil samples was taken in the winters of 1910–11 and 1912–13.

In the winter of 1910–11, a series of soil samples was taken weekly for four weeks beginning March 15. Another set was taken on April 29, and the last set on May 29, two and one-half months after the disappearance of the park snow. Twelve samples were taken on each date in the park, in 3 different locations and at 4 different depths. In the forest 16 samples were taken on each date, from 4 different locations, and at 4 different depths. The 4 depths at which samples were taken during this winter were as follows: 0–1 inch, 1–4 inches, 8–10 inches, 16–18 inches.

During the winter of 1912–13, the first set was taken on March 24 and the last on June 13, in the midst of the dry season. A total of five sets was taken at intervals of approximately three weeks. In the park two localities were always chosen, one a slight north slope and the other a slight south slope, and a total of 20 samples was taken at each of the following depths: 4–8 inches, 12–16 inches, 24–32 inches.

In the forest two samples were taken at each of the above depths in each of the following four situations: (1) South side of trees; (2) north side of trees; (3) directly under trees; (4) openings.

Thus the important conditions in the forest were represented. All the park and forest samples were weighed, and heated in a soil oven at 100°C. until a practically constant weight was reached. The moisture percentages are based upon the weight of the dry soil.

Soil temperature.—Since special soil thermometers were not available, soil temperatures were determined by means of common exposed thermometers suspended within a wooden casing. It was found impracticable to take readings during the winter months, because the casings became filled with water, which, on freezing, made it impossible to raise the thermometer for reading. For this reason the measurement of soil temperatures did not begin until May 1. The thermometers were placed at a depth of 2 feet. Readings were taken daily between 8 and 9 a. m.

Frost.—The capacity of a soil to absorb water from its surface is affected to a certain degree by the presence or absence of frost. During the winter of 1910–11 frost depths were determined in January, February, and March. In the forest they were determined in the openings and under the crowns. Determinations were also made during the winter of 1912–13. In the forest the following situations were selected: North side of trees, south side of trees, and openings. In the park two situations were chosen, one on a slight north slope and the other on the level.

Snow reconnoissance.—After all the snow had disappeared from the park in the spring of 1913, three 10-acre plats of *level* forest land adjacent to the park were covered by a snow reconnoissance at intervals of 4, 8, and 12 days, respectively, in order to determine the actual amount of snow retained by the forest per acre. It was thought better to distribute the reconnoissance on three different areas at three different times rather than to confine all three periodic measurements to one area. The maximum depth and the average depth of the drifts encountered was determined. In addition, the length and width of

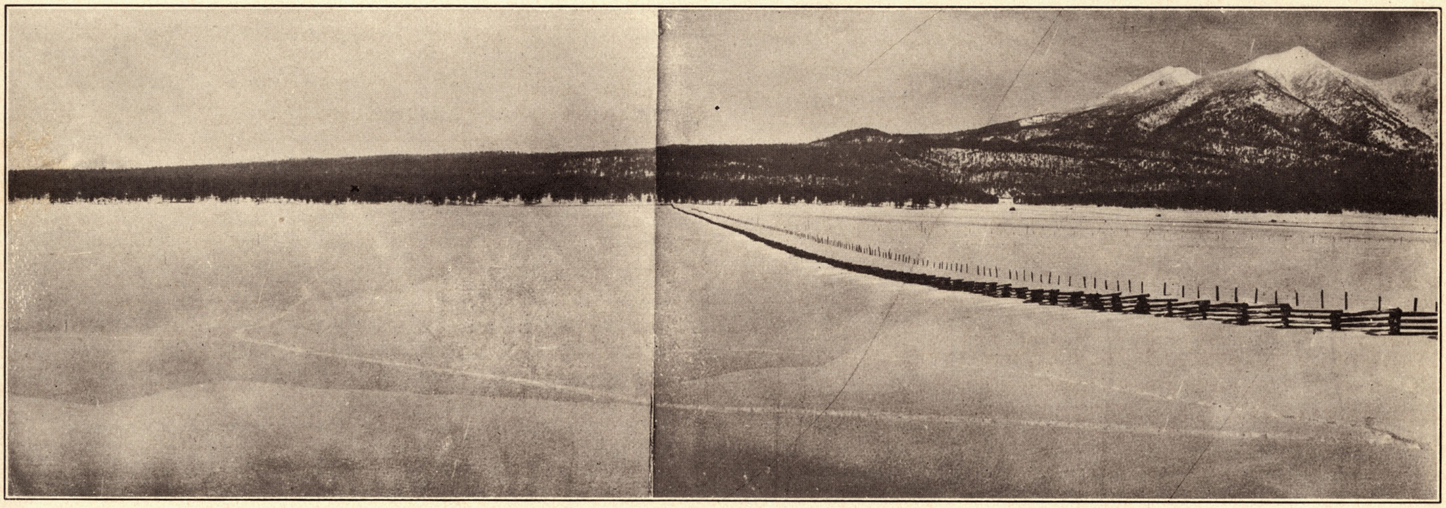

FIG. 1.—General view of Fort Valley "park" and the surrounding country, February 21, 1911. Note the snow banked on the windward side of the rail fence. Meteorological stations No. 2 (park) and No. 3 (forest) are indicated by X.

FIG. 2.—Details of meteorological station No. 3 (forest).

the drifts were measured. The water equivalent of the snow composing the drifts was ascertained at the end of each 4-day interval.

METEOROLOGICAL RECORD.

Three permanent meteorological stations are maintained at the Fort Valley Experiment Station, and since two of these are immediately adjacent to the stake lines the daily readings taken there were of great value in this study. Daily meteorological records have been kept at these three stations since January 1, 1909, by means of standard instruments furnished for this purpose by the United States Weather Bureau and installed under the supervision of its officials.

Station 1 is situated at the edge of the timber on the west side of the park, with an elevation of 7,260 feet. The apparatus consists of a maximum and minimum thermometer, a Robinson cup anemometer, a sling psychrometer, a wind vane, and an evaporation pan.

Station 2 is situated in the open park at an elevation of 7,250 feet above sea level, and has practically the same equipment as Station 1; in addition, a series of snow stakes at which snowfall and melting measurements were taken for this study. (See fig. 3.)

Station 3 is located in a typical virgin stand of western yellow pine, 1,450 feet from the edge of the park, at an elevation of 7,350 feet. The forest snow stake line begins at this station and extends in a general southerly direction to the edge of the park. (See fig. 2.)

COMPARISON OF SNOWFALL IN PARK AND FOREST.

General character of snowfall.—During normal years, according to United States Weather Bureau records at Flagstaff, Ariz., which have been maintained for 13 years, the snowfall of the winter season begins about the middle of November. The first snows, up to the middle of December, are usually light and wet and disappear very rapidly. The succeeding snowfalls are heavy and dry and keep the ground covered to a depth of 1 to 3 feet throughout the winter. Usually about the beginning of March the spring thaw sets in, causing the snow to disappear in about two weeks. Light snows occur throughout the month of March and in the early part of April. Like the first snows, these are moist, and melt soon after they reach the ground.

TABLE 1.—*Comparison of precipitation for the five winter seasons, 1908–09 to 1912–13.*

[Average of park and forest.]

Winter.	Total snowfall (Station 2).	Water equivalent.	Rain.	Total precipitation.
	Inches.	*Inches.*	*Inches.*	*Inches.*
1908–09	78.6	....	....	15.87
1909–10	71.1	8.69	1.90	10.59
1910–11	28.35	3.80	9.10	12.90
1911–12	63.2	6.55	1.62	8.17
1912–13	72.8	7.95	0.19	8.14

This brief comparison shows clearly the abnormal character of the winter of 1910–11, and the normality of the winter of 1912–13, the winter during which this study was conducted in most detail. In the winter of 1909–10, a normal one, the observations were made along the same general lines by H. D. Burrall at this station. Since the results obtained by Mr. Burrall correspond to the results during a subsequent normal and abnormal winter, the conclusions drawn in this study can be taken as applicable to this region under average conditions.

Winter precipitation, 1910–11, and 1912–13.—The winter of 1910–11 was very abnormal, and was characterized by a small total snowfall and frequent interspersing rains. The first snowfall, occurring on November 5, 1910, was light and moist, and melted the same day. Succeeding snowfalls during November were of the same character. A permanent snow cover was not established until December 20, increasing to 6.1 inches in the park and 5.7 inches in the forest until December 28. Aside from a snowfall of 1.1 inches on December 31, the snow cover gradually decreased until a heavy rain and thaw set in on January 11. Showers, now and then changing into a wet snow, occurred frequently from then on to February 4. The effect upon the snow cover was exactly that of the later spring thaws; the entire park covering disappeared within a short time, while but a few banks of snow remained in the forest openings. A fall of 3.1 inches on February 4 reestablished the snow cover which attained its maximum depth of 7.7 inches on March 4. Four days later, on March 8, the spring thaw set in and bared the park in five days. The last snowfalls in March were light and wet and, like the first snows, melted rapidly. Heavy drifting occurred but twice, during February, before an east wind blowing 50 miles an hour. Naturally more snow was displaced in the park than in the forest, since the park snow was exposed to the full unbroken force of the wind.

The winter of 1912–13 was a fairly normal winter, although preceded on October 5 by an abnormally early snow of 6 inches. This snow was very wet, accompanied by much rain and high temperatures, and entirely disappeared within a few days. On October 30 and 31 two light snows occurred, but this fall rapidly disappeared. Two light snows occurred during November, neither of which formed even a temporary snow cover. On December 8 a snowfall of 4.3 inches established a snow cover which was thereafter maintained throughout the winter, reaching a maximum depth of 23 inches in the park on February 28. Slight thaws occurred at irregular intervals during February and the first two weeks of March. The heavy spring thaw set in on March 26, and by April 3, one week later, the park snow had entirely disappeared. In the forest numerous heavy drifts of snow persisted for several weeks. Tables 2 and 3 present some of the details for each storm passing over Fort Valley Experiment Station during the winter of 1910–11 and 1912–13.

TABLE 2.—*Snowfall and wind movement for each storm during the winter of 1910–11.*

[Rainfall during winter=9.1 inches.]

Date.	Depth of snowfall.		Water equivalent of mean for park and forest.	Wind velocity.		Wind direction.
	Park.	Forest.		Park.	Forest.	
	Inches.	*Inches.*	*Inches.*	*Mis./hr.*	*Mis./hr.*	
Nov. 5	0.01	0.01	T.	4.0	2.0	e.
15	0.68	0.68	0.06	1.0	0.5	w.
16	0.05	0.05	T.	2.5	1.5	w.
19	0.05	0.05	T.	2.5	1.5	e.
Dec. 20	2.6	2.5	0.19	7.0	2.5	w.
27	5.0	4.7	0.4	2.5	1.5	w.
28	0.1	0.1	T.	2.5	1.5	e.
31	1.1	1.2	0.1	3.5	2.0	w.
Jan. 9–11	1.6	1.7	0.4	6.0	2.5	sw.
11	0.4	0.5	T.	3.5	2.0	e.
21	T.	T.	T.	4.0	2.0	sw.
Feb. 1	0.9	1.0	T.	7.0	3.0	sw.
4	3.2	3.1	0.97	2.0	1.0	sw.
13	3.0	3.0	0.4	6.0	3.0	sw.
14	0.2	0.6	T.	13.0	4.5	sw.
15	2.1	1.8	0.17	6.5	2.5	sw.
16	0.4	0.4	0.05	1.5	1.5	sw.
20	1.4	0.9	0.14	6.0	3.0	w.
26	2.9	2.1	0.40	4.0	3.5	sw.
Mar. 3	1.8	1.5	0.15	2.0	1.5	w.
4	0.9	0.8	0.2	4.5	2.5	sw.
6	0.9	0.6	0.2	....	....	w.
11	0.16	0.16	....	9.0	3.0	sw.
Total	29.45	27.45	3.83	*4.6	*2.2	

* Averages.

TABLE 3.—*Snowfall and wind movement for each storm during the winter of 1912-13.*

[Rainfall during winter=0.19 inches.]

Date.	Depth of snowfall.		Water equivalent.		Wind velocity.		Wind direction.
	Park.	Forest.	Park.	Forest.	Park.	Forest.	
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Mis./hr.*	*Mis./hr.*	
Oct. 5	6.0	6.0	0.96	0.96	5.0	2.0	sw.
30	0.75	0.75	0.04	0.04	5.0	4.0	sw.
31	0.50	0.50	0.02	0.03	7.0	2.0	ne.
Nov. 11	0.4	0.4	0.11	0.11	5.0	3.0	w.
20	0.65	0.65	0.15	0.14	5.0	4.0	sw.
Dec. 1	0.4	0.4	0.07	0.07	2.5	1.5	w.
2	1.5	1.4	0.27	0.27	2.0	1.0	s.
3	T.	T.	T.	T.	2.5	2.0	w.
7	1.2	1.3	0.11	0.10	13.0	7.0	ne.
8	4.3	4.3	0.42	0.45	5.0	1.5	se.
9	T.	T.	0.02	0.02	4.5	1.0	ne.
15	0.15	0.1	0.02	0.01	7.5	4.0	sw.
21	0.1	0.1	0.02	0.02	7.0	2.5	s.
Jan. 5	0.6	0.6	0.02	0.02	3.0	2.5	w.
10	6.9	6.7	0.54	0.53	3.5	3.0	sw.
15	2.0	2.0	0.26	0.21	5.0	3.0	sw.
16	1.3	1.3	0.17	0.19	11.0	4.0	sw.
Feb. 1	1.9	1.9	0.18	0.18	2.5	2.0	s.
7	0.4	0.3	0.07	0.07	3.0	1.5	ne.
8	2.6	2.7	0.35	0.34	2.0	1.5	s.
18	0.2	0.2	0.03	0.03	7.5	4.0	sw.
19	2.6	2.6	0.23	0.21	7.5	3.0	sw.
20	0.7	0.7	0.08	0.08	4.0	2.5	sw.
21	12.0	11.7	1.29	1.22	6.5	3.0	sw.
22	2.9	2.9	0.25	0.27	7.0	3.0	sw.
23	0.7	0.7	0.08	0.08	3.0	2.0	s.
24	1.1	1.1	0.12	0.19	6.0	2.5	sw.
25	3.2	3.2	0.40	0.41	4.0	1.5	ne.
26	3.9	3.7	0.28	0.24	11.0	4.0	sw.
27	1.6	1.6	0.12	0.12	7.0	3.0	sw.
Mar. 12	3.5	3.4	0.33	0.32	8.0	3.5	sw.
13	0.5	0.5	0.06	0.06	12.0	5.5	sw.
14	0.3	0.3	0.03	0.03	6.0	2.5	n.
20	0.8	0.8	0.11	0.11	10.0	4.0	nw.
21	0.5	0.5	0.07	0.07	6.0	3.5	sw.
24	2.3	2.2	0.19	0.19	9.0	3.5	sw.
25	3.4	3.9	0.38	0.41	8.0	4.0	sw.
26	1.0	1.0	0.09	0.09	2.0	2.0	sw.
Apr. 2	0.2	0.2	0.04	0.04	10.0	4.5	sw.
Total	73.05	72.6	7.98	7.93	*6.2	*2.9	

* Averages.

Comparison of amount of snowfall in forest and park.—This has been the subject of investigation at the Fort Valley Experiment Station since the winter of 1908-9. Table 4 shows the relative snowfall in the park and the forest for the past four winters.

TABLE 4.—*Comparison of snowfall in park and forest at Fort Valley.*

Winter of—	Forest.		Park.	
	Snow.	Water equivalent.	Snow.	Water equivalent.
	Inches.	*Inches.*	*Inches.*	*Inches.*
1909-10	69.95	8.49	72.6	8.88
1910-11	27.45	3.82	29.45	3.82
1911-12	63.9	6.74	62.4	6.36
1912-13	72.6	7.93	73.05	7.98

This record for four winters is very brief and shows no constant relation between amount of snowfall in the forest and in the park. During the latter part of the winter of 1908-09, W. R. Mattoon [1] made a yet briefer study of this subject in this locality, and concluded that the snowfall was somewhat greater in the forest because of the accelerated wind velocity over the parks, resulting in a lighter deposition of snow, a case similar to the deposition of silt in stream courses. The winter of 1911-12 also shows slight excess in the forest, but in 1909-10, 1910-11, and 1912-13 there was a slight excess in the park. So far as such studies permit, the conclusion which may be drawn is that there is no appreciable difference in the amount of snowfall in forest and park.

A great deal of snow is occasionally deposited in the tree crowns, especially during storms with very light winds and wet snow. Most of this snow is subsequently blown off into the openings within the first few days. The amount of snow thus accumulating in the crowns and subsequently blown off can not be accurately measured because of the fact that when temperatures are high enough to cause rapid melting the snow falls off in solid masses which break through the surface of the snow already on the ground, and do not increase the depth of the snow layer. A little of the snow retained in the crowns evaporates, and never reaches the ground. Temporary retention of snow in the tree crowns makes an accurate forest-park snowfall comparison practically impossible. Exclusive of this temporarily retained snow, the forest and park snowfall records for four consecutive winters show practically no difference for the two situations.

Comparison of distribution of snowfall in park and forest.—The character of deposition in the forest and the park differs greatly. In the park the snow falls in a layer practically uniform in depth except for banking on the windward and leeward sides of rail fences. In the forest most of the snow is deposited in drifts in the openings, accompanied by a very light deposit directly under the crowns of the trees. However, during a very light, dry snowfall the difference in deposition under and outside of the crowns is slight.

Tables 5 and 6, which present records of the winters 1910-11, and 1912-13, clearly show that on those occasions in the forest the snowfall directly under the crowns of the trees was very much less than on areas outside a crown cover, and that in the park the snow fell in practically an even layer.

TABLE 5.—*Total snowfall at each stake from Dec. 1, 1910, to Apr. 1, 1911.*

PARK.

Stake No.	Total snowfall.	Remarks.
	Inches.	
1	25.6	Stakes equidistant from one another in the open park.
2	29.5	
3	27.6	
4	28.9	
5	32.5	
6	32.6	
7	27.7	
8	27.1	
9	28.9	
10	28.4	

FOREST.

1	31.3	Slight protection from tree crowns.
2	16.4	Almost entirely surrounded by tree crowns.
3	29.7	Little protection from crowns.
4	18.5	Entirely protected by tree group on southwest.
5	32.5	No protection.
6	28.8	Protection from northwest which is unimportant.
7	26.8	Slight protection from group of reproduction.
8	26.9	Slight protection on west; protected on northwest.
9	23.8	Fairly well protected from all directions.
10	33.7	No crown protection.

[1] Mattoon, W. R., Effects of Forest upon Snow waters. Forestry quarterly, 7, 246.

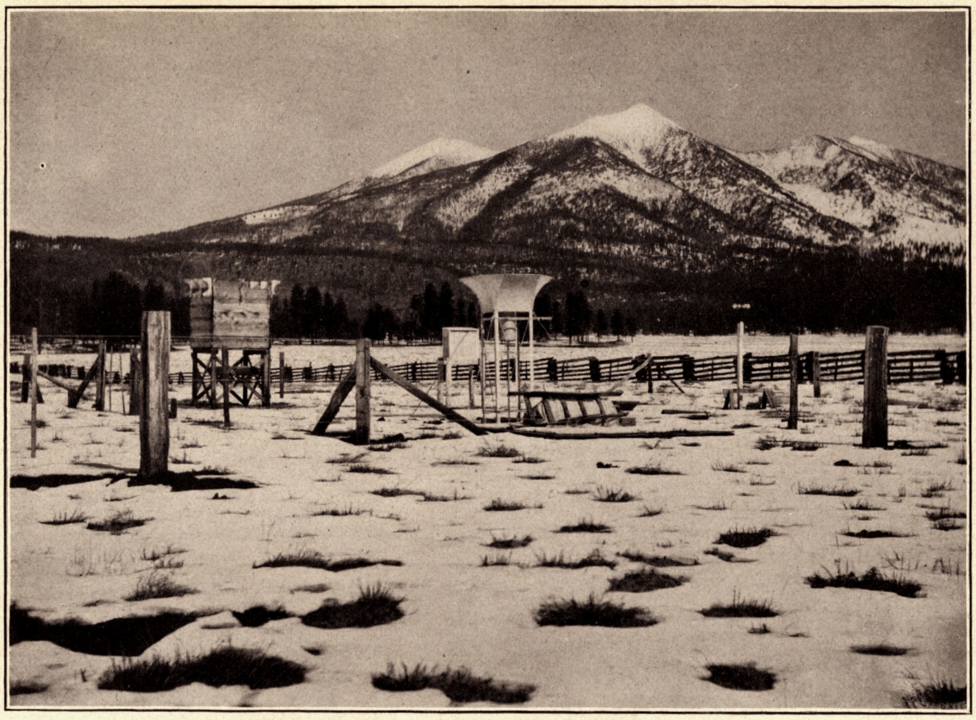

FIG. 3.—Details of meteorological station No. 2 (park). This view shows both the Bigelow "snow bin" and the Marvin shielded snow gage.

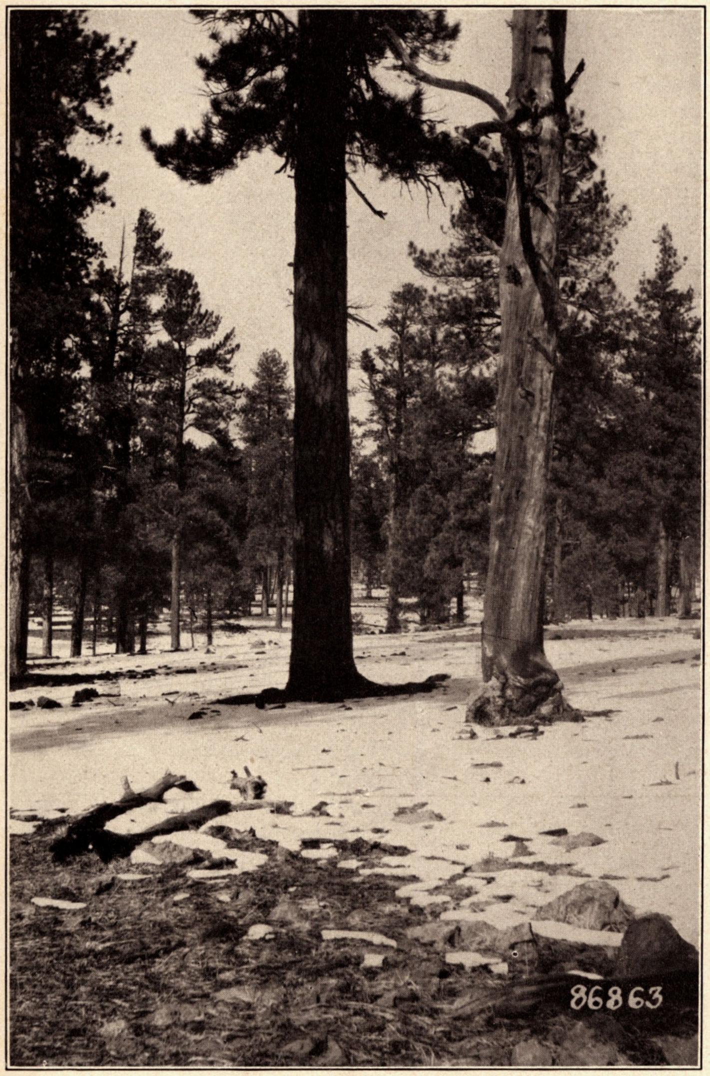

FIG. 4.—Slight influence of a high narrow crown (yellow pine) and that of a dead tree with no crown.

FIG. 5.—Greater influence of a low wide crown (blackjack).

EFFECT OF TREE CROWNS ON THE ACCUMULATION OF SNOW (FIGS. 4 AND 5).

TABLE 6.—*Total snowfall at each stake from Dec. 1, 1912, to Apr. 2, 1913.*

PARK.

Stake No.	Total snowfall.	Remarks.
	Inches.	
1	66.5	Stakes set at 66-foot intervals in the open park. Thus conditions at all the stakes are practically the same. Stakes 4, 5, 6, and 7 are on a slight north slope.
2	66.6	
3	65.8	
4	66.7	
5	62.2	
6	64.5	
7	65.6	
8	64.4	
9	61.5	
10	62.2	

FOREST.

Stake No.	Total snowfall.	Remarks.
	Inches.	
1	76.2	Practically no protection.
2	70.2	No trees in immediate vicinity. Group some distance to southwest.
3	50.6	Located in midst of group of trees.
4	61.1	Partial protection from crowns on north.
5	72.5	No protection in opening.
6	59.1	Protected by trees in all directions except northeast.
7	69.0	No trees in immediate vicinity.
8	62.2	Partial protection.
9	45.7	Located in middle of dense tree group.
10	78.1	No protection.

Detailed records of the snowfall at each stake for the individual storms during the winters 1910–11 and 1912–13, not included in this report, bring out the great diminution in snowfall directly under the tree crowns and the concentration of the greater part in the openings. In the park, on the other hand, there was only a slight difference between snowfall at the various stakes. These deep drifts in the openings of the forest persisted several weeks after all the snow in the park had disappeared. Data as to frequency and size of these drifts in the forest after total disappearance of snow in the park is given in Tables 15 and 16.

COMPARISON OF MELTING IN PARK AND FOREST.

Melting begins as soon as the snow falls, the degree depending upon several factors, chief of which is the temperature of the soil and atmosphere. Further influencing factors are slope, exposure, and radiation. Two distinct periods must be considered in the process of melting, namely, the slow melting throughout the winter and the sudden rapid melting during the spring thaws.

Winter melting.—During the winter melting is much faster in the forest than in the park, due mainly to the higher minimum and mean temperatures in the forest during these months. Table 7 gives the average of four years' records at the Experiment Station.[2]

TABLE 7.—*Comparison of temperatures in park and forest.*

[Mean=½ (max.+min.).]

1909-1912	Forest (station 3).			Park (station 2).		
	Mean max.	Mean min.	Mean.	Mean max.	Mean min.	Mean.
	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
December	39.6	11.1	25.3	40.8	2.6	21.7
January	41.9	16.6	29.2	42.9	10.3	26.6
February	41.9	13.4	28.6	42.8	8.1	25.4
March	47.3	22.6	34.9	47.3	17.0	32.3

[2] G. A. Pearson. A Meteorological study of parks and timbered areas in the western yellow pine forests of Arizona and New Mexico. MONTHLY WEATHER REVIEW, Oct. 1913, 41: 1615–1629.

In the forest only a thin layer of snow is deposited under the tree crowns, and when this is once broken melting progresses more rapidly. Very important in the rate of melting is the radiating influence of trees, reproduction or new growth, surface rocks, and leaf litter. Even after the heaviest snowfall the ground directly under the tree crowns is almost bare within a few days. These bare areas give a further impetus to the melting of snow immediately around them. They are devoid of frost long before any situation in the park, and hence are capable of absorbing the water resulting from the melting of the snows late in the winter. This point will be brought out in detail later.

Because melting is so much more rapid in the forest before the spring thaws, the amount of snow in the forest at any given time during the winter is often less than in the park. This, together with the comparative rate of melting in the park and forest, is brought out by Tables 8 and 9.

TABLE 8.—*Fluctuations of snow cover in park and forest from Dec. 27, 1910, to Mar. 22, 1911.*

Date.	Average depth along stake line.		Water equivalent.		Date.	Average depth along stake line.		Water equivalent.	
	Park.	Forest.	Park.	Forest.		Park.	Forest.	Park.	Forest.
1910.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	1911.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Dec. 27	6.0	5.6			Feb. 14	4.8	5.3		
28	6.1	5.7			15	6.8	7.1		
29	3.8	4.3			16	7.2	7.5		
30	3.6	3.9			18	4.6	6.0		
31	4.7	5.1			19	3.6	5.5		
1911.					20	4.9	6.2		
Jan. 5	4.1	4.0			21	4.6	5.8		
6	3.8	3.7	0.7	0.6	22	4.4	5.6	1.06	1.03
7	3.8	3.5			23	4.3	5.5		
8	3.7	3.1			25	4.0	6.3		
9–11	4.3	4.7			26	7.0	7.2		
12	3.5	3.9			28	6.1	6.5		
13	3.0	3.5	1.16	0.91	Mar. 1	5.3	5.8		
14	2.9	3.3			2	4.9	5.5	1.5	2.1
15	2.8	3.2			3	6.8	7.0		
16	0.6	2.2			4	7.7	7.8		
17	1.1	2.7			5	5.5	5.8		
18	0.3	2.4			6	6.4	6.4		
19	0.1	2.3			7	6.0	5.9		
20	0.0	2.1			8	5.7	5.4	2.51	2.33
21	0.0	2.0			9	3.7	3.9		
26	0.2	2.5			10	1.8	3.3		
27	0.0	2.2			11	0.2	3.4		
28	0.0	2.0			12	1.6	2.9		
Feb. 1	0.9	1.6			13	0.5	2.0		
2	0.0	0.6			14	0.0	1.8		
3	0.0	0.6			15	0.0	1.7		
4	3.1	3.7			16	0.0	1.3		
8	2.9	3.3			17	0.0	0.9		
9	2.7	2.9			18	0.0	0.8		
10	2.6	2.4			20	0.0	0.6		
12	1.8	1.7			21	0.0	0.5		
13	4.5	4.7			22	0.0	0.4		
					23	0.0	0.2		

TABLE 9.—*Fluctuations of snow cover in park and forest from Dec. 1, 1912, to Apr. 3, 1913.*

Date.	Average depth along stake line.		Date.	Average depth along stake line.	
	Park.	Forest.		Park.	Forest.
1912.	*Inches.*	*Inches.*	1912.	*Inches.*	*Inches.*
Dec. 1	0.4	0.4	Dec. 20	0.6	1.0
2	1.5	1.4	21	0.5	1.0
3	1.4	1.0	22	0.6	1.0
4	1.1	0.7	23	0.5	1.0
5	1.0	0.5	24	0.5	1.0
6	0.7	0.4	25	0.5	1.0
7	0.6	0.4	26	0.5	1.0
8	1.5	1.5	27	0.3	0.8
9	4.8	4.8	28	0.0	0.5
10	4.0	4.2	29	0.0	0.4
11	3.1	3.2	30	0.0	0.3
12	2.9	2.9	31	0.0	0.2
13	2.8	2.6	1913.		
14	2.2	1.9	Jan. 1	0.0	0.2
15	1.7	1.5	2	0.0	0.2
16	1.3	1.2	3	0.0	0.2
17	1.0	1.1	4	0.0	0.2
18	.9	1.0		.8	0.9
19	.8	1.0			

TABLE 9.—*Fluctuations of snow cover in park and forest from Dec. 1, 1912, to Apr. 3, 1913*—Continued.

Date.	Average depth along stake line.	
	Park.	Forest.
1913.	*Inches.*	*Inches.*
Jan. 6	0.8	0.9
7	0.8	0.9
8	0.7	0.8
9	0.6	0.7
10	7.3	7.2
11	7.5	7.3
12	6.2	6.0
13	5.6	5.1
14	5.2	4.4
15	4.7	4.0
16	6.4	5.5
17	7.2	6.7
18	6.9	6.3
19	6.7	5.8
20	6.5	5.7
21	6.5	5.7
22	6.4	5.6
23	6.3	5.5
24	6.3	5.5
25	6.3	5.5
26	5.9	5.4
27	5.7	5.4
28	5.6	5.3
29	5.6	5.3
30	5.4	5.0
31	5.3	4.9
Feb. 1	5.2	4.7
2	6.4	6.6
3	6.3	6.4
4	6.2	5.9
5	6.0	5.4
6	5.6	5.0
7	6.1	4.6
8	7.3	6.8
9	6.4	5.9
10	6.0	5.4
11	6.0	5.2
12	5.9	5.2
13	5.9	5.1
14	5.8	4.8
15	5.7	4.3
16	5.4	3.7
17	4.3	3.1
18	3.8	2.7
19	3.6	2.5
20	6.3	5.3
21	7.0	5.9
22	19.0	17.4
23	19.0	16.1
Feb. 24	16.5	14.0
25	16.5	14.4
26	18.6	16.5
27	21.5	20.2
28	22.9	21.3
Mar. 1	20.9	18.8
2	19.2	15.8
3	18.3	15.0
4	17.0	13.8
5	16.1	12.5
6	15.0	11.4
7	14.0	10.4
8	13.1	9.7
9	12.4	9.1
10	9.3	8.3
11	8.8	7.7
12	12.1	10.7
13	11.3	9.4
14	10.4	9.1
15	9.8	8.9
16	9.8	8.3
17	9.1	7.6
18	8.3	6.8
19	8.8	7.2
20	9.4	7.7
21	8.7	6.6
22	7.1	5.3
23	6.2	4.8
24	8.5	7.0
25	11.7	11.0
26	13.4	10.9
27	12.0	8.7
28	10.4	6.9
29	8.7	5.6
30	7.1	4.3
31	5.8	3.2
Apr. 1	3.3	2.1
2	1.6	1.4
3	0.6	1.2
4	0.0	0.9
5	0.0	0.8
6	0.0	0.6
7	0.0	0.4
8	0.0	0.3
9	0.0	0.2
10	0.0	0.1
11	0.0	0.0

Water equivalent of snow cover in forest and park during winter of 1912–13.—Weekly determinations of the water equivalent of the total snow cover in the forest and the park during the winter of 1912–13, although showing a greater total water equivalent for the park, failed to reveal any constant difference in *snow density* in the two situations for that season. In the park the snow is more fully exposed to the direct rays of the sun and the action of the wind and therefore, theoretically at least, the snow in the park should be more compact.

Table 10 shows the result of the weekly determination of water equivalents.

TABLE 10.—*Water equivalent and density of snow cover in forest and park Dec. 8, 1912, to Apr. 1, 1913.*

Date of determination.	Total snow depth.		Total water equivalent.		Snow density.	
	Park.	Forest.	Park.	Forest.	Park.	Forest.
1912.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Per cent.*	*Per cent.*
Dec. 8	1.5	1.5	0.13	0.13	8	8
15	1.7	1.5	0.34	0.27	20	18
23	0.5	1.0	0.10	0.30	20	30
1913.						
Jan. 2	0.0	0.2	0.0	0.08	....	40
9	0.6	0.7	0.11	0.11	18	16
16	6.4	5.5	0.77	0.56	18	10
24	6.3	5.5	0.80	0.58	13	11
Feb. 1	5.2	4.7	0.77	0.51	15	11
8	7.3	6.8	1.12	1.03	15	15
15	5.7	4.3	1.00	0.94	18	22
24	16.5	14.0	1.73	1.46	11	10
Mar. 1	20.9	18.8	2.11	1.95	10	10
8	13.1	9.7	1.76	1.58	14	16
15	9.8	8.9	1.95	1.69	20	19
23	6.2	4.8	2.01	1.13	32	24
Apr. 1	3.3	2.1	1.17	0.75	36	36

Spring thaws of winters 1910–11 and 1912–13.—The spring thaws begin when maximum temperatures attain about 50°F., which usually occurs shortly after the 1st of March. During the season 1910–11 the spring thaws set in about March 8. The gradual melting in the forest showed only a slight increase in its rate; but lacking the protection afforded by the forest canopy against extremes of temperature, the park snow entirely disappeared in about a week. The low minimum temperatures of the park caused the formation of an ice crust at the base of the snow layer late in the winter and in the early spring. The condition was observed particularly during the winters of 1908–9 and 1909–10, in which the ice crust attained a thickness of from 1 to 2 inches. The frequent fluctuation of the maximum temperatures, the large amount of rain, and the light snowfall during the winter of 1910–11 allowed but a very thin layer of ice, hardly more than one-fourth inch thick, to form beneath the snow. On March 13 no snow remained in the park, except a small drift along the rail fences, while banks still occupied most of the openings in the forest, both on slopes and level situations. (See figs. 8 and 9.) The last drifts within from one-fourth to one-half mile of the edge of the park disappeared on March 23, but farther back in the forest banks of snow were still visible on April 10. A series of photographs was taken every other week along the line of stakes in the park and in the forest to illustrate these differences in melting; four of them are reproduced as figures 6–9.

During the winter 1912–13 the spring thaws started about March 27, and by April 3 every trace of snow in the park had disappeared, while snow still was present directly along the forest stake line till April 10, and persisted in the form of drifts in the openings on the north sides of tree groups immediately adjacent to the stake line till April 16, as shown by Table 11.

TABLE 11.—*Measurement of snowdrifts along stake line in forest.*

Date.	1 [1]	2 [2]	3 [3]	4 [4]	5 [5]	6 [6]	Remarks.
1913.	Maximum depth of snow in inches.						
Mar. 29	15.6	19.5	13.0	10.2	13.7	11.5	
30	14.5	18.5	10.5	8.5	11.0	9.5	
31	13.5	17.4	8.9	7.9	9.8	8.0	
Apr. 1	10.8	15.0	8.0	7.5	8.8	5.5	
2	9.5	13.8	6.7	6.1	7.6	4.1	
3	9.0	12.4	5.6	5.1	5.7	2.3	
4	8.5	11.8	5.0	4.7	5.3	1.5	
5	6.2	10.0	3.1	2.8	2.1	0.0	No snow in park.
6	5.0	9.1	2.2	1.7	0.9	....	
7	3.8	8.2	1.0	0.4	0.0	....	
8	2.5	7.4	0.4	0.0	....	....	
9	2.0	6.8	0.0	....	....	....	
10	1.6	6.3	....	....	....	....	
11	1.2	5.7	....	....	....	....	
12	0.8	4.6	....	....	....	....	
13	0.3	3.9	....	....	....	....	
14	0.0	1.8	....	....	....	....	
15	....	1.1	....	....	....	....	
16	....	0.0	....	....	....	....	

[1] Situated 25 feet west of stake 1.
[2] Situated 30 feet west of stake 1.
[3] Situated between stakes 4 and 5.
[4] Situated between stakes 5 and 6.
[5] Situated between stakes 6 and 7.
[6] Situated immediately south of stake 7.

This persistence of drifts, in the forest after entire disappearance of snow in the park was also observed at the Fort Valley Experiment Station in the winter of 1908–9. The following is quoted from a report by W. R. Mattoon:[3]

> In the timber throughout this region there remained on April 25, a considerable quantity of snow in sheltered situations, favorable for late melting, while the last trace of snow had disappeared from the park by April 12.

These drifts occur entirely in the openings, usually on the north side of a group of trees, and are rather long and narrow—the longer dimension, as a rule, extending from east to west. The snow in the drifts is not of an even

[3] Mattoon, W. R. Effect of forest upon snow waters. Forestry quarterly, No. 3, 7: 246.

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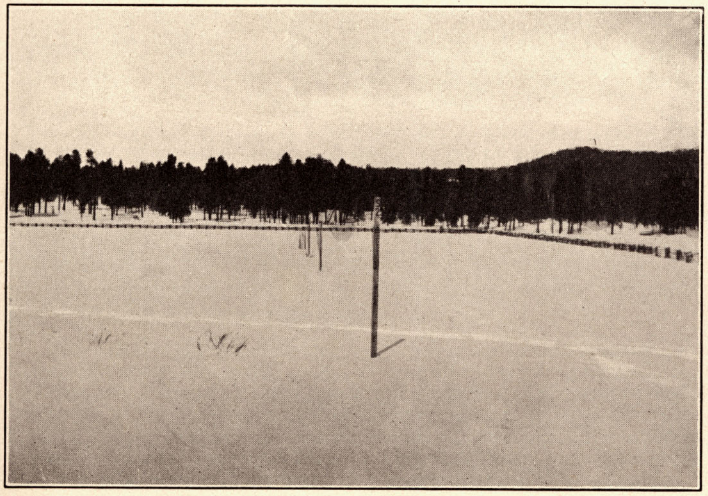

FIG. 6.—Looking northward in park, February 16, 1911.

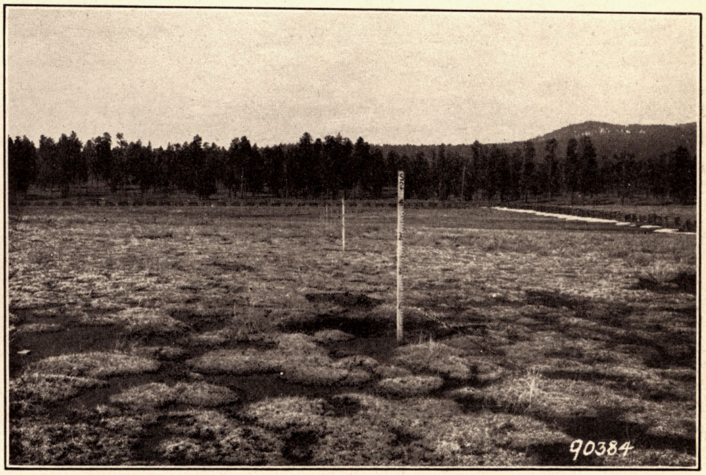

FIG. 8.—View looking northward in park, March 16, 1911.

FIG. 7.—View in forest, February 16, 1911.

FIG. 9.—View in forest, March 16 1911.

depth, nor is the snow composing it of uniform density. At the edges the snow is usually of the least depth and the greatest water equivalent, while in the middle it lies deepest and has the least water equivalent. Melting is much more rapid at the edges than in the middle of the drift, and for this reason the drift decreases not only in average snow depth, but also in length and width.

On April 3, 1913, the last snow disappeared in the park, but large drifts of snow persisted for several weeks in the openings between the tree groups in the forest. In order to determine the amount of snow thus retained by the forest, a snow reconnoissance of three sample 10-acre plots of forest was made at intervals of four days, as explained above under "Method and character of observations" (p. 115). Tables 12, 13, and 14 show clearly the advantage of a given forested area over a similar bare area in the retention of snow. The western yellow-pine forest, however, is a very open one, and therefore the retention of snow is not as marked as is the case in denser forests, such as the fir forest which Prof. Church, of the Mount Rose Observatory, at Reno, Nev., describes. The following is quoted from Prof. Church's article "Relation of forests to conservation of snow":[4]

> The ideal forest from the viewpoint of conservation (of snow) is the one that can conserve the maximum amount of snow until the close of the season of melting. Such a forest should not be dense enough to prevent the snow from reaching the ground, and yet should be sufficiently dense to afford ample shelter from sun and wind. The fir forest possessing a maximum number of glades or a forest of mountain hemlock meets these requirements both theoretically and practically.

TABLE 12.—*Snow-drift reconnoissance in forest adjoining Fort Valley Park made on Apr. 8, 1913, or five days after total disappearance of snow in park.*

Greatest depth of drift.	Average depth of drift.	Dimensions.	Area of drift.	Volume of drift.
Inches.	*Inches.*	*Feet.*	*Square feet.*	*Cubic feet.*
10.0	6.0	30×150	4,500	2,250
5.0	3.5	20×25	500	146
8.5	5.2	15×40	600	260
9.0	5.0	15×60	900	375
12.9	7.3	35×150	5,250	3,194
4.0	3.5	5×10	50	15
7.3	4.0	20×70	1,400	467
7.5	4.1	15×40	600	205
9.6	6.0	30×120	3,600	1,800
8.4	5.0	35×60	2,100	875
5.5	3.0	20×65	1,300	325
5.1	2.8	15×20	300	70
9.6	7.0	25×320	8,000	4,666
6.5	4.5	10×35	350	131
9.3	6.5	10×20	200	108
8.3	6.0	15×15	225	113
Cubic feet of snow retained on 10 acres				15,000

Snow density determination April 8, 31.6 per cent, or 1 inch snow=0.316 inches water; 15,000 cubic feet snow with density of 31.6 per cent distributed on 10 acres is equivalent to 0.13 inch or 3,545 gallons of water per acre.

TABLE 13.—*Snow-drift reconnoissance in forest adjoining park Apr. 12, 1913, nine days after total disappearance of snow in park.*

Greatest depth of drift.	Average depth of drift.	Dimensions of drift.	Area of drift.	Volume of drift.
Inches.	*Inches.*	*Feet.*	*Square feet.*	*Cubic feet.*
5.5	4.0	15× 70	1,050	350
8.3	6.1	30×120	3,600	1,830
9.8	5.1	20× 60	1,200	510
10.5	7.4	15× 45	675	416
4.8	4.1	5× 5	25	9
5.7	4.0	25× 30	750	250
7.0	5.5	20×125	2,500	1,375
5.0	4.4	10× 15	150	55
5.2	4.0	30×150	4,500	1,500
9.2	4.7	15× 60	900	352
8.6	5.5	25× 45	1,125	516
5.1	3.6	15× 20	300	90
4.6	2.5	15× 75	1,125	234
5.0	2.8	10× 20	200	47
5.5	3.9	15× 25	375	122
Snow retained on 10 acres				7,656

Snow density determination Apr. 12, 37.5 per cent, or 1 inch snow=0.375 inch water; 7,656 cubic feet snow with density of 37.5 per cent distributed on 10 acres is equivalent to 0.08 inch, or 2,150 gallons of water per acre.

[4] Church, J. E., jr., Scientific American Supplement, No. 1914, 74: 155.

TABLE 14.—*Snow-drift reconnoissance in forest adjoining Fort Valley Park Apr. 16, 1913, thirteen days after total disappearance of snow in park.*

(Area C.)

Greatest depth of drift.	Average depth of drift.	Dimensions of drift.	Area of drift.	Volume of drift.
Inches.	*Inches.*	*Feet.*	*Square feet.*	*Cubic feet.*
4.5	2.9	15×40	600	145
8.3	5.0	15×65	975	406
9.5	7.2	20×25	500	300
4.6	3.2	10×20	200	53
8.7	6.0	15×30	450	225
3.6	2.1	10×25	250	44
3.1	1.7	10×20	200	28
3.4	1.5	10×15	150	19
4.0	3.5	5× 5	25	7
6.6	4.2	20×60	1,200	420
Snow retained on 10 acres				1,647

Snow density determination Apr. 16, 39.0 per cent, or 1 inch snow=0.39 inch water; 1,647 cubic feet snow with density of 39.0 per cent distributed on 10 acres is equivalent to 0.02 inch, or 481 gallons of water per acre.

Condition of the soil.—The park soil derives much less benefit from the winter's precipitation than does the forest soil, since the extremely low temperatures prevailing in the park throughout the winter cause the soil to freeze to a considerable depth. This condition of the soil and the ice layer on top of it, prevent the absorption of the great amount of snow water suddenly liberated by the spring thaws. The higher mean temperatures and the accumulation of leaf litter around the trees prevent deep freezing in the forest, as shown in the following tables. This allows the water to soak in readily.

TABLE 15.—*Depth of frozen ground in park and forest, winter 1910-11.*

Date.	Depth of frozen ground.		
	Park.	Forest.	
		Under crowns.	In openings.
1911	*Inches.*	*Inches.*	*Inches.*
Jan. 5....	9.7	5.0	6.5
Feb. 23...	6.3	2.5	3.0

Observations made on March 15, 1911, showed a surface layer of soft mud 2 inches thick in the park, with a frozen layer 1½ inches thick below. The soil inside the forest was completely thawed out and saturated with snow water.

TABLE 16.—*Depth of frozen ground in park and forest, winter of 1912-13.*

Date.	Park.	Forest.[1]		
		North side of trees.	South side of trees.	Open.
1912.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Dec. 10	12.1	5.4	5.2	8.3
1913.				
Jan. 5	18.2	9.1	9.4	14.0
Jan. 21	17.0	7.5	6.8	10.5
Feb. 18	29.5	13.0	0.0	21.5
Mar. 24	23.1	3.6	0.0	8.2
Mar. 27[2]	20.2	0.0	0.0	7.0

[1] Depths given are the mean of two determinations.
[2] First day of the spring thaws.

The small amount of frost on the south side of the trees is attributable directly to the intense insolation, together with the presence of leaf litter, which protects the soil against freezing. The leaf litter, as shown in Table 20, is deeper on the north side than on the south side of the trees, but this added protection is more than offset by the decrease in insolation on the north side. The openings beyond the immediate influence of the trees have the advantage of full sunlight, but lack the protection of leaf litter. Snow cover is also an important factor. If the ground is frozen before a heavy snowfall, the frost is apt to be retained longest where the snow is deepest, but if the ground is not frozen when the snow falls, the snow cover retards freezing.

TABLE 17.—*Depth of leaf litter and ground cover.*

Forest.			Park.
North side of trees.	South side of trees.	Openings.	
Inches. 1.5	*Inches.* 1.0	Light leaf litter, little grass.	Short grass cover.

Disposition of snow waters.—In the forest absorption keeps pace with melting during the winter, so that the soil is soon saturated during the first thaws. This results in a limited amount of surface run-off from the slopes. In the winters of 1910–11, and 1912–13 this run-off started earlier in the forest and continued later than in the park. However, it can in no way be compared with the enormous amount of surface run-off from the park. There the water is not able to penetrate into the frozen soil and is more or less prevented from running off freely by the still unmelted snow, so that it forms a slush with the latter and greatly hastens the final melting. The water then goes off with a rush, draining toward the Rio de Flag at the southeast corner of the park. During the spring of 1911 the Rio de Flag ran 10 to 12 feet wide and from 12 to 18 inches deep for 4 days, and continued to run as a small stream for about 10 days. This latter was the run-off from the more protected snows at the edge of the timber. Practically the same condition existed in the spring of 1913. Because there is no mutually independent forest drainage area and park drainage area of equal size in the vicinity, no exact comparative measurements of surface run-off in the park and the forest could be made. In the park it was also noticed that small bodies of standing water subject to rapid evaporation were present everywhere on level situations where it could not run off, or because of the frozen condition of the soil could not seep into the ground.

During the winter of 1908–09, W. R. Mattoon made observations on the disposal of the snow waters in the park and the forest at this station. The following is quoted from his report.[5]

The surface run-off in the two situations is interesting from the standpoint of water conservation. By April 1, bodies of water overlying the ice sheet had collected in the depressions in the park, and a good-sized stream was flowing at the outlet. No perceptible surface run-off from the forest (over the locality under consideration) occurred during March. The days of April 1, 2, and 3 were unusually warm and quiet, and resulted in the only run-off from the forest during the entire spring. The amount was insignificant compared to the total water content of the snow mass. It is well to state, incidentally, that the writer made daily trips between the two measuring stations, which afforded an opportunity for noting the conditions.

Influence of exposure.—A great contrast in the rapidity of melting is exhibited between north and south exposures. Protected from the sun's rays, there is practically no melting on north slopes during the winter months. With the approach of spring, however, the constant high maximum temperatures result in a very gradual melting. Actual measurements showed snow banks on short northerly slopes within the forest to persist 10 days after their disappearance on level situations and southerly slopes.

[5] Forestry quarterly, No. 3, 7: 246.

It was noted that a forested north slope retains its snow much longer than a nonforested one. The north slope of Crater Mountain, which rises only a few hundred feet above the south side of the park upon which it borders, offered opportunity for observations on a forested north slope and an exactly similar bare north slope, both at the same elevation. On April 2, one week after the beginning of the spring thaws of the winter of 1912–13, determinations of snow depth were made as follows: A north and south line was followed on both the bare and forested north slope, and measurements of depth taken at exactly 1 chain intervals for 21 chains, the north and south extent of the bare slope. A record was made regardless of whether snow was encountered or not. Table 18 shows a striking balance in favor of the forested north slope over the similar bare slope.

TABLE 18.—*Comparison of snow retained on a forested north slope and on a similar bare slope of Crater Mountain, Apr. 2, 1913.*

Chain No.	Depths of snow.	
	Forested slope.	Similar bare slope (same elevation).
	Inches.	*Inches.*
1	16.5	5.6
2	9.0	3.2
3	9.2	3.3
4	2.5	4.7
5	7.0	2.5
6	7.5	3.5
7	9.2	1.9
8	0.0	6.0
9	10.0	0.0
10	18.2	7.5
11	11.1	4.5
12	9.8	8.1
13	14.3	3.7
14	13.1	2.6
15	11.0	5.1
16	20.5	8.2
17	17.5	4.3
18	19.0	2.9
19	14.3	5.1
20	11.0	0.0
21	21.7	3.2
Total depth	252.4	83.9
Mean depth	12.0	3.9
Total water equivalent	3.05	1.05

The snow on the bare slope showed an average water equivalent of 0.269 inches water per inch of snow, against 0.254 inches for the forested area.

On April 10 the bare slope was entirely stripped of snow, while the forested slope contained drifts in the openings between the tree groups until May 2.

No other similar bare and forested areas with exposure other than north were available for observation. However, on April 2, 1913, the efficacy of the various forested slopes of Crater Mountain was determined by taking snow depths at chain intervals for 21 chains on the various exposures. The general results were as shown in Table 19.

TABLE 19.—*Depth of snow on various forested slopes of Crater Mountain, Apr. 2, 1913.*

Slopes.	Mean depth of snow.
	Inches.
North slope	12.00
East slope	5.21
West slope	3.65
South slope	1.23
Level situation on top of Crater Mountain	1.52

These figures indicate that the north and east slopes are most efficient in snow conservation, and that the west and south slopes are relatively less important.

MOISTURE CONTENT OF SOIL AFTER DISAPPEARANCE OF SNOW.

Factors influencing absorption and retention of soil moisture.—Determinations of the mositure content of the forest and park soils after the disappearance of the snow cover in the winters of 1910–11 and 1912–13 show a marked advantage for the former soil. Several factors bring about this difference in the absorptive and retentive capacity.

As already shown in Table 16, the frost depth in the forest is much less than in the park during the winter and spring. Obviously, therefore, the forest soil is in a better condition to absorb the water resulting from the melting of the snow. Again, in the forest there is no thick ice layer between the soil and the snow cover such as is found in the park. Soon after even the heaviest snowfall, the soil beneath the tree crowns is laid bare, which gives it an opportunity to thaw out or freeze quickly and to absorb the water resulting from the snow in the adjacent openings.

Not only is more moisture absorbed by the forest soil, but more retained, due to decreased evaporation resulting from decreased wind movement, protection afforded by leaf litter, and lower soil temperatures. Investigations of the evaporation from a free water surface in the park and the forest have been carried on for four years, and the results show that during the growing season—the only time that evaporation records can be successfully taken because of freezing of the water in winter—evaporation in the forest is only 70 per cent of that in the park.

Four years of records at the experiment station show that the wind movement in the forest is only 50 per cent of that in the park. This decreased wind movement in the forest is one of the most [?] important factors in the difference between park and forest evaporation.

With the exception of the openings, the forest soil is covered by a mulch made up of fallen needles. This covering reduces considerably the amount of evaporation from the soil, as has been conclusively shown by Prof. Ebermayer[6] in Bavaria.

A very important factor in the decreased evaporation from the forest soil is its lower temperature as compared with the park soil. The mean soil temperatures at a depth of 2 feet for May, June, and July, 1913, are given in Table 20.

TABLE 20.—*Comparison of soil temperature at a depth of 2 feet in forest and park, May 1–July 31, 1913.*

Month.	Mean temperature.	
	Park.	Forest.
	°F.	°F.
May	52.1	41.7
June	61.1	49.2
July	65.9	54.8

The soil temperatures in the forest were taken on the north side of a group of trees, representing the maximum shade. While measurements in the openings undoubtedly would show higher temperatures, the fact that the greater part of the forest soil is shaded makes it evident that the soil temperature for the forest as a whole must be less than in the park.

[6] Quoted or cited by Raphael Zon in "Forests and Water in the Light of Scientific Investigation". Appendix V, p.232, of the final report of the U. S. National Waterways Commission.

Soil-moisture determinations.—The following tables, 21, 22, 23, present the results of soil-moisture determinations made during the spring of 1911 and 1913:

TABLE 21.—*Moisture contents of forest and park soils, spring of 1911.*

[Per cent of moisture.]

Date.	Depth of sample.									
	0–1 inch.		1–4 inches.		8–10 inches.		16–18 inches.		Average.	
	Forest.	Park.	Forest.	Park.	Forest.	Park.	Forest.	Park.	Forest.	Park.
Mar. 15	38.5	29.0	31.5	26.4	26.3	23.7	27.0	28.1	30.8	26.8
23	37.0	21.7	30.6	23.5	26.0	23.7	30.1	27.9	30.9	24.2
30	35.9	16.1	29.5	21.2	24.9	23.3	31.1	27.0	30.4	21.9
Apr. 7	34.4	9.6	27.6	18.4	23.8	22.6	31.2	26.5	29.3	19.3
16	31.8	3.5	24.9	15.7	22.0	21.2	30.5	25.1	27.3	16.4
29	26.7	1.0	20.3	12.2	19.1	18.3	28.6	24.0	23.7	13.9
May 29	3.8	0.7	8.7	6.1	14.0	13.1	22.1	19.0	12.2	9.7

TABLE 22.—*Moisture contents of forest and park soils, spring of 1913.*

[Per cent of moisture.]

Date.	Depth of sample.							
	4–8 inches.		12–16 inches.		24–32 inches.		Average.	
	Forest.	Park.	Forest.	Park.	Forest.	Park.	Forest.	Park.
Apr. 14	29.2	21.7	27.6	23.9	28.9	23.4	28.6	23.0
May 3	23.1	19.4	29.9	20.4	30.9	22.6	28.0	20.8
23	19.4	15.8	19.4	17.0	22.3	18.4	20.4	17.0
June 13	12.5	7.9	21.2	14.5	25.0	21.5	19.6	14.6

The results given for the forest in Table 22 are means of soil samples from the following situations: South side of trees; north side of trees; directly under trees; openings.

TABLE 23.—*Moisture contents of soils in open and shaded situations in forest, spring of 1913.*

[Per cent of moisture.]

Date.	Depth of samples.							
	4–8 inches.		12–16 inches.		24–32 inches.		Average.	
	Open.	Shaded.	Open.	Shaded.	Open.	Shaded.	Open.	Shaded.
Apr. 14	23.7	31.0	22.8	29.1	23.9	30.6	23.5	30.2
May 3	19.8	24.2	21.4	32.8	24.2	33.0	21.8	30.0
May 23	14.5	21.0	18.3	19.7	20.8	22.8	17.9	21.2
June 13	6.5	14.4	11.3	24.5	19.0	27.0	12.3	21.9

The few soil-moisture determinations presented in summary by Tables 21–23, show the following points—

(1) The surface layers of the forest soil absorb and retain for a much longer period a greater amount of snow-water than the corresponding soil layers of the park.

(2) In the forest itself, the areas covered by leaf litter and protected by the tree crowns absorb and retain a greater quantity of soil moisture than do the bare forest openings. Hence a denser forest than one of western yellow pine would be more efficient as a retainer of soil moisture.

Tables 21, 22, and 23 are the result of soil-moisture determinations made during the spring of 1911 and the spring of 1913.

CONCLUSIONS.

The conclusions drawn from this study may be summarized as follows—

I. Snowfall:

1. We have found no appreciable difference in the total snowfall on a forested and a nonforested area.
2. The slight variations in snowfall which occur are due to differences in the wind velocity and temporary retention of snow on the tree crowns.
3. The distribution of the snow on the ground differs greatly on a forested and nonforested area. The "park" snow lies in an even layer, while the forest snow is distributed in a shallow layer under the trees and in deep drifts in the openings.
4. The amount of snow retained by the tree crowns and entirely lost by evaporation is small.
5. During the winter the snow density in the park and forest is practically the same.

II. Melting:

1. The rate of melting during the winter is greater in the forest than in the park, due to higher minimum and mean temperatures, lighter disposition of snow under the tree crowns, and radiation from the trees, reproduction, rocks, and logs. Because of this more rapid winter melting, the average depth of snow in the forest during the winter is less than in the park.
2. The spring thaws cause a rapid melting of the park snow, while the rate of melting of forest snow is but slightly accelerated. The park is stripped of its snow cover within a few days, which may result in flooding, while heavy drifts of snow persist throughout the adjacent forest for two weeks or more after the total disappearance of the park snow. On account of the very open character of the western yellow pine forest it is not nearly as efficient as a snow conserver as more dense forests with smaller openings between the tree groups.

III. Disposal of the snow waters:

1. At the time of the spring thaws, the soil in the park is frozen to a considerable depth and is covered by an ice layer which prevents thawing. Therefore, when the park snow melts during the spring thaws, the surface run-off is excessive, and absorption of soil moisture by the park soil comparatively small.
2. In the forest the snow disappears more gradually, the soil is almost entirely thawed out, and therefore the snow waters become seepage water instead of run-off.
3. The forest soil, aside from absorbing more moisture, retains it better than the park soil, due to protection from evaporation by decreased wind movement, shade, and leaf litter.

The foregoing conclusions make it evident that the value of forest cover in the conservation of snow waters is great, even when that forest cover is of such an open and broken character as the typical western yellow-pine forest on which observations were made in this study. For this reason, the somewhat denser forests in other regions would have a much more marked influence on snow and snow-water conservation than the yellow-pine forest of the Southwest. Again, forests can be too dense to be of much value as snow conservers, since if there are few openings the snow will have difficulty in reaching the ground and a comparatively large portion may be evaporated from the tree crowns.

In a region where water is as scarce as in the Southwest, the preservation of the forests is of the utmost importance. This applies not only to watersheds from which cities or irrigation projects derive their supply, but to all forests. The flow of springs and wells is dependent largely upon the forest which makes it possible for the rain and snow waters to percolate slowly through the soil instead of running off on the surface. The forest, by checking wind and evaporation, and tempering the extremes of heat and cold, favors the growth of other vegetation and creates conditions more hospitable to man and beast.

By proper management of our forests it is possible not only to maintain but to augment their influence. The effect of increasing the density of the stand is evident. This may be done by encouraging natural reproduction and by planting. The prevention of fires will assist in maintaining and increasing the density of the forest, and will conserve the leaf litter and other organic matter which has been shown to be of great value in absorbing and retaining water. The prevention of overgrazing will have the same effect. Heavy cutting, especially on steep slopes, must be avoided, and cutting must always be consistent with the requirements for natural reproduction. Fortunately, the conditions which favor the conservation of water on the national forests may be obtained without sacrifice. The interests of water conservation go hand in hand with those of timber production. It is not necessary to prohibit the cutting of timber on a watershed, because in scientific forestry the cuttings are so regulated that the density of the forest as a whole remains normal. Moderate grazing will not ordinarily injure a watershed, and such grazing regulations as are ordinarily necessary to conserve the water supply are also those which are necessary to maintain the productivity of the range. Cultivation, while hastening the melting of snow, places the soil in a receptive condition for water and should be favored, except on the steep slopes, where there is danger of erosion. Under the administration of the Forest Service all of these interests are being harmonized. It is the purpose to utilize every material resource on the national forests in the interest of the greatest public good. It is possible to increase the productivity of the timber, the forage, and water resources and to use them forever without danger of exhaustion.

REMARKS BY THE WEATHER BUREAU.

In seeking to disclose cause-and-effect relations between observed phenomena by the analysis and comparison of statistical data, it is often considered to be a good plan to have no preconceived theory or bias as to how the results should come out, since it is well known that statistical data can be made to support numerous propositions that have no real basis in science, logic, or nature. On the other hand, it may also lead to error if, in such studies, one disregards generally accepted physical principles broadly applicable to the problem.

The foregoing paper by two professional foresters presents a discussion of two fundamental propositions:

(1) The relative amounts of snowfall over a limited extent of forest-covered area and an open or unforested adjacent area.

(2) The relative rates of melting, in the spring, of the snow on the ground in the forest and in the open.

The data available for study are fairly complete observations for five winter seasons, during one of which the snowfall was comparatively slight. It is obvious to the meteorologist that any difference in amount of precipitation over forest and park, revealed by only five years of observations, may be most rationally explained on either the basis of wholly accidental differences in local distribution of precipitation during the short period of the observations or on residual and uneliminated errors of measurement which are well known to be very large for snowfall, rather than on the forest influence per se.

The study of the relative rate of melting of snow cover lying in the open, in the forest or elsewhere, should be approached from the point of view of the heat supply. Some snow is always vanishing from a given cover, blanket, or bed by the process of sublimation, but the process of melting is primarily a question of heat supply. The beds of snow lingering in the shadows of our houses, barns, and other shelters long after other snow exposed to unobstructed sunshine has melted, are familiar to all of us. So long as the air temperature remains near the freezing point or passes but little above it the melting of the snow in a given location is slow or rapid according to the amount of radiant heat or sunshine it receives and absorbs. This heat supply will be much greater on a surface sloping favorably southward or southwestward. The absorption will be greater in the case of snow darkened and discolored by dirt, soot, or otherwise; greater in the case of a snow surface broken up into irregular pockets as compared with snow whose surface is in a clean and glazed mirror-like condition. When the general weather conditions of a region are such that a relatively warm spell sets in, the snow cover then on the ground over the park and in the forest, for example, will be subjected to relatively high atmospheric temperatures for some days. The rates of melting must then be largely dominated by the heat supply derived from the air itself. Direct solar radiation then exerts a subordinate influence. This will be especially the case if the onset of warm weather is attended with warm rains. In these cases the influence of the forest may be of little consequence.

A forest obviously intercepts a great or a little part of the solar radiation incident upon it according to its density and character. Consequently a part only of the radiant heat reaches the ground and snow thereon is prevented from receiving the same quota of radiant heat as similar snow in the open. Observations are not needed to tell us that the melting of snow in the forests is necessarily delayed under these conditions; we have that knowledge *a priori*. The numerical data should serve, rather, to quantitatively fix the relative rates, a problem for which the present data are quite inadequate if results are expected to be representative of anything more than the particular and limited conditions under which the data were collected.

When we view the question from the point of heat supply we see at once that the forest as such is a mere incident of the conditions. The fundamental principles outlined in the foregoing as applicable broadly to the problem of the melting of snow in the forest and in the open have not received quite the attention they deserve by Messrs. Jaenicke and Foerster, and their presentation of the case permits the nontechnical reader to gain the unwarranted impression that the influence of the forest is general and fundamental rather than indirect and incidental. It is easily conceivable that the radiant heat over a park or open field could be partly cut off by the installation of artificial devices arranged to intercept solar radiation to almost any specified extent and thus artificially conserve the melting of the snow, much as the forest is found to do. This suggestion is offered simply to direct attention to the question of the heat supply as controlling the phenomena under study rather than a forest *per se*. The proposal as a commercial proposition, seems no more visionary than other efforts made by man to alter and modify nature's customary course.—[C. F. M.]

The measurements and observations carried out by Messrs. Jaenicke and Foerster in the foregoing paper are a valuable contribution to our observations on the effects of forests on various climatological factors in the Coconino National Forest. However, I think that the authors sometimes draw conclusions that are not sufficiently supported by the data they present.

In their introductory pages the authors state that the two areas they study are "alike in all respects except that one was forested and the other naturally treeless." It is very difficult to establish the fact that two areas are alike in all respects. Further, the very fact that trees grow on one area and do not naturally grow on the other area is in itself an evidence that there is some sort of difference between the two areas.

On page 116 it is stated that the method of determining the water equivalent of snow was to cut out a cylinder of snow by means of the 8-inch raingage overflow cylinder turned upside down and melt with a definite volume of water. This method is recommended by the Weather Bureau to cooperative and other observers as a simple one for determining the water value of freshly fallen snow, although it may sometimes be used for the measurement of the entire layer of snow on the ground. The method was tried out in the early days of the work of the Weather Bureau in cooperation with the Forest Service at the Wagon Wheel Gap station, but was abandoned as inconvenient, not sufficiently reliable, and not adapted to the large number of observations made in that work. The results obtained in the present case are surprisingly consistent, considering the method, and I believe that by exercising unusual care the observers have overcome the difficulties inherent in the simple apparatus they used.

On page 119 occurs the statement "During the winter melting is much faster in the forest than in the park." This comes as a surprise to many of us. Winter melting results largely from sunshine or direct insolation; spring melting is due to a combination of sunshine with higher air temperatures. While it is not the intention to dispute our authors' statement, it may properly be here pointed out that if their discovery shall be substantiated by further evidence it will overturn many theories as to what ought to happen in this connection.

The information concerning the slopes is not sufficient to permit a proper analysis of the data presented in Table 18 and the figures may be susceptible of explanation in more than one way. Slight differences in slope may have been unrecognized or the location may have been such that high winds carried the snow from the bare slope to the forested slope.

As to the conclusions on page 124, the statement under II, 2, that "heavy drifts of snow persist throughout the adjacent forest for two weeks or more after the total disappearance of the park snow" is hardly borne out by the numerical data given at the bottom of Tables 12, 13, and 14. It is there stated that the forest retained 0.13 inch water equivalent for 5 days after total disappearance from the park, 0.08 inch was retained for 9 days, while only 0.02 inch was retained for 13 days. The conclusions concerning the relative efficiency of forests of western yellow pine are not supported by any comparisons with other covers.—[B. C. K.]

ATMOSPHERIC INFLUENCE ON EVAPORATION AND ITS DIRECT MEASUREMENT.

By Prof. BURTON EDWARD LIVINGSTON.

[Dated: Johns Hopkins University, Laboratory of Plant Physiology, Feb. 8, 1915.]

Although evaporation has long been of interest to students of meteorology and climatology this subject seems never to have assumed prime importance in either of these branches of science. The rarity of comparative evaporation records in the United States represents a condition of affairs closely paralleled in other countries and indicates that but few workers have been vitally interested in the measurement of this climatic feature. A glance through the literature of atmometry (1) shows that evaporation has frequently attracted the attention of individuals and that its literature includes the names of many well-known students of weather and climate. Very many methods for the direct measurement of evaporation have been described from time to time during the last two centuries, but none of these has been generally adopted by weather services for any long period. This may have been due in part to numerous apparent difficulties inherent in atmometry itself, and these difficulties have aroused hopes that evaporation may become possible of calculation from data of other climatic factors. Such hopes have led some of the most able students of atmospheric physics to attempt the experimental derivation of mathematical expressions for intensity of evaporation in terms of temperature, atmospheric humidity, and wind velocity. The problem thus suggested is fascinating to the mathematical physicist, and the inadequacy of some one evaporation formula has frequently given rise to still further attempts in the same general direction, while the direct measurement of this factor has naturally been discouraged by the hope that reliable means for its calculation may soon be forthcoming.

Within the last decade, however, there has arisen a pronounced and ever increasing interest in direct atmometric measurements, an interest primarily due to the activities of plant physiologists, plant and animal ecologists, and students of agriculture and forestry. These workers have been led to study evaporation by the extreme importance of evaporation into the surrounding air in determining the activities of many organisms, especially plants and lower animals. It was early appreciated that the water relation seems to furnish a more satisfactory basis for many ecological interpretations (of the relations holding between organism and environment) than does any other single one of the various environmental relations. Plants show by their very structure and appearance their relations to the moisture conditions of their surroundings, while their temperature, light, and mechanical relations are not immediately nearly so patent and must be subjected to experimentation before even approximate determination may be possible. This point is well illustrated by the fact that ecological classifications of plant forms has generally been based upon the water relation. Simple inspection suffices to distinguish, with considerable precision, between xerophytes, mesophytes, and hydrophytes (representing various degrees of *xerophyly*) and these categories form the basis most commonly employed for the classification of vegetation forms. It is apparently obvious to the eye of the plant anatomist that a broad-leaved, deciduous forest must require more moisture than does a forest of needle-leaved conifers, and he sees just as clearly that prairie grasses, chaparral, and such forms as cacti and yuccas require less water than do ordinary forests, their water requirement decreasing in the order named. Natural vegetation areas and agricultural provinces have so far been charted mainly on this sort of basis. On the other hand, no very serious attempts have yet been made to classify vegetation forms with regard to their temperature or light relations (their different degrees of *thermophily* and of *photophily*, if such terms may be allowed).

When plant ecology began to emerge from its first descriptive and taxonomic phase attention was soon directed to the measurement of environmental conditions as these are related to plant activities. The most obvious, if not the most important, of these conditions, as far as the atmosphere is directly concerned, is the evaporation, and the instrumentation of plant habitats has made greater progress with this factor than with any other. Such progress has been made possible through a new development of atmometry.

Aside from this biological interest, it should here be noted that evaporation has long attracted the attention of irrigation and hydraulic engineers, from whose reservoirs evaporated water represents a considerable loss, even in humid regions. Also the direct loss of soil moisture by evaporation is frequently of great importance in agricultural operations, and this matter has not been neglected by students of this field.

The direct measurement of evaporation has recently attracted more attention from students of meteorology and climatology, who are coming to realize the practical futility of attempts to calculate the intensity of this factor from measurements of other atmospheric conditions.

The present paper deals with some considerations brought forward by the study of evaporation in its biological relations, but these considerations may not be without interest to climatologists, especially to those dealing with agricultural climatology.

Some general principles of atmometry.

The evaporating power[1] of the air here denotes its power to remove (or to allow the removal of) water vapor from any given exposed surface of liquid or solid water. This power is to be measured as the time rate of such removal (2).

It should be emphasized at once that the water surface from which evaporation proceeds often plays as great a rôle in the rate of water loss as do the atmospheric conditions. If different sizes, shapes, or kinds of evaporation pans, or pans containing different amounts of water, are exposed to the same complex of aerial conditions, it has been repeatedly shown that the rate of water loss per unit of surface differs for the different pans employed. If there is but slight difference between two pans, the rates of loss may appear to be the same for short-time periods, due to lack of precision in the measurements, but with pronounced differences between the pans there is no difficulty in establishing this principle.

The rate of loss in such cases is not at all directly proportional to the area of water surface exposed. *The rate*

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[1] Prof. Livingston does a service in thus emphasizing the needs for intercomparable atmometers and uniform exposures so far as the latter are attainable. The Weather Bureau feels, however, that it must protest against the use of the inaccurate and misleading expression "evaporating power of the air." As Prof. Livingston himself here defines the term, the air has no power to evaporate a liquid, only to hinder that evaporation in a greater or lesser degree.—*Editor*.